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**AIRCREW WORK/REST CYCLES  
IN BOXTOP 1/95**



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## ABSTRACT

This paper reports on activity log data collected during Boxtop 1/95. Boxtop aircrew flew a fixed three-shift, three-airplane schedule repeating every 48 hours. A two-page activity log was used to collect data from 41 aircrew and wrist actigraphs were used to provide a second source of information from 18 aircrew. Information was collected on sleep length, hours awake before flying, hours continuously awake, mood, alertness and sleep quality. Significant differences were found between shifts, particularly the night shift which scored lower on mood, sleep quality, and alertness on awakening. Afternoon crews were up longer before flying and at their last touch-down of a work cycle, on average, than morning or night crews.

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## EXECUTIVE SUMMARY

This report describes the collection of aircrew work/rest cycle data during Boxtop 1/95. The purpose of the field study was threefold: validate field data collection as a method of studying work/rest cycle data; collect baseline data in an operational environment; and provide feedback to the Commander of Air Transport Group on operators' concerns about work/rest schedules.

Boxtop 1/95 supplied fuel to Canadian Forces Station Alert using three CC-130 aircraft operating on a round-the-clock basis. Aircrew nominally flew a three round-trip, 16-hour day, with the cycle repeating every 48 hours. All 45 aircrew were asked to complete a two-page daily activity log. Four crews were asked to wear activity monitors (actigraphs) on their wrists. Over three hundred sleep logs were collected during the operation, and actigraph data were retrieved for a period of four days.

It was found that aircrew slept longer after a day flying than before a day of flying - 8 hours 20 minutes vs. 6 hours 17 minutes on average. A pattern of sleep length and bed-time developed that alternated between work days and rest days. Such significant changes in sleep patterns from one day to the next make it difficult to adapt to a 24-hour circadian rhythm. A large number of sleeps were disturbed, some more than five times. Fully 29% of all sleep interruptions reported were due to reasons of noise or discomfort.

For morning, afternoon and night crews respectively, the mean number of hours awake 30 minutes before last touch-down of the day was: 15 hours 4 minutes, 17 hours 19 minutes, and 16 hours 11 minutes. Afternoon crews were up the longest including extreme values of 23 hours 55 minutes, 24 hours 35 minutes, and 25 hours 5 minutes. These data and others collected in the study highlight striking differences between aircrew shifts.

Night shifts appear to be disadvantaged when comparing ratings reported for mood, sleep quality and alertness on awakening. Night crews were awake for less time before flying than afternoon crews, because they tended to nap from two to four hours before flying. However, given their poorer sleep quality ratings, it is questionable whether the naps were completely effective.

In conclusion, the study validated the concept of collecting human factors data in the field using activity logs and wrist-based activity monitors; baseline data were collected. The data presented in this paper contain a number of warning signs for Boxtop planners. The three-trip day places great demands on aircrew and some shifts are disadvantaged. There is evidence that aircrew are not adapting well to the schedule and the environment, even after two weeks.

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## AIRCREW WORK/REST CYCLES IN BOXTOP 1/95

### INTRODUCTION

*Purpose.* This report discusses the field data collection of work/rest cycle data from CC-130 aircrew - to validate field data collection methods and instruments; to collect baseline data on a Boxtop operation; and to provide feedback to the Commander of Air Transport Group on CC-130 human factors issues. The data were collected during Boxtop 1/95, a two-week (17-27 April, 1995) airlift operation to deliver fuel from Thule Air Force Base, Greenland, to Canadian Forces Station (CFS) Alert.

*Background.* On October 30, 1991 CC-130 aircraft 130322 crashed near CFS Alert during a Boxtop operation. Because of this and other accidents in the CC-130 fleet, a human factors study was sponsored by the Canadian Forces (CF) Air Command (AIRCOM). The study is the joint responsibility of Air Transport Group (ATG) and the Defence and Civil Institute of Environmental Medicine (DCIEM). The study mandate centred on developing measures of aircraft and aircrew performance to be tested and validated using the CF CC-130 simulator. The effort reported herein is a collateral report to the main study in response to an early request from ATG that DCIEM provide informed comment on their guidelines for work/rest cycles. It is recognized that other important human factors issues are of concern to ATG personnel.

The Canadian Forces Air Transport Group dedicates three CC-130 Hercules aircraft to each Boxtop operation, along with several crews. For Boxtop 1/95, three shifts of three crews were scheduled and within a shift, crews were called out one and one-half hours apart to reduce the possibility of congestion on the ramp in Alert. The 'morning' shift call-out times were 6:00 a.m., 7:30 a.m. and 9:00 a.m., followed by the 'night' shift call-outs at 10:00 p.m., 11:30 p.m., and 1:00 a.m. The final three crews in the 48-hour cycle - the 'afternoon' shift - were called at 2:00 p.m., 3:30 p.m., and 5:00 p.m. the day after the morning shift began (see Annex A for the Boxtop 1/95 crew call-out schedule).

Ideally, each crew flies three round-trips during a shift. Aircraft shuttle around the clock on the 90-minute flight between Thule and Alert. Weather and breakdowns often affect the flow of the operation and the crew duty days. In Boxtop 1/95, 27 trips were cancelled because of bad weather and 7 were cancelled because of aircraft problems, out of a planned 145 trips<sup>1</sup>.

Boxtop aircrew are drawn from the six squadrons that fly the CC-130 aircraft in different roles (strategic and tactical transport, rescue, and training). The Boxtop

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<sup>1</sup>In this paper, 'trip' and 'round-trip' are used interchangeably.

operations staff, which works out of Thule, also makes up a spare aircrew in the event that one person cannot fly; during Boxtop 1/95 crew substitutions occurred twice.

Aircrew work/rest cycles in long-haul operations have been of concern for many years [1,2,3]. The condition known as fatigue is a typical result of poor work/rest schedules. To paraphrase Bartlett [4], fatigue can be defined as:

*a deterioration in performance over time, under normal conditions, that leads to unwanted results.*

Fatigue has been classified into several types (e.g. [1,2]), however it is generally accepted that mental fatigue and physical fatigue have different causes and results. In flying, mental fatigue is the greater threat to safe operations<sup>2</sup> and as described in [1] the results can include: a decrease in the ability to recognize a changing situation; delays in correcting a situation once it has been recognized; and increased 'sloppiness' in making corrections.

More recently, Belland and Bissell [5] examined fatigue in U.S. Navy flying operations during post Gulf War patrols of the southern no-fly zone over Iraq. Survey data were collected on fatigue for 125 aircrew that flew four to six hour sorties daily, in single and dual seat jet aircraft (e.g. F/A-18, A-6.) Several physical symptoms of fatigue were reported by aircrew, including headache, back pain, and drowsiness. Aircrew also reported increases in small mistakes and insomnia. Aircrew reported that having a 'no fly' day every four or five days helped them catch up lost sleep.

The measurement of aircrew performance in-flight, without interfering with the task at hand, presents significant difficulties. In one early study by McFarland and Edwards [6], the authors took advantage of extra crew to administer physiological and psychological tests on a trans-Pacific flight. However, in modern military flying, there are few opportunities available to perform such comprehensive testing in the field. More recent studies have concentrated on the use of questionnaires and tests administered on the ground.

DCIEM also has experience studying work/rest cycles in long range airlift operations. A 1970 study by Innes [3] used a fatigue checklist to make pre- vs. post-flight comparison for several long flights (legs of 7 to 12 hours duration) in Hercules and Yukon aircraft. Results showed that subjective fatigue information could be distinguished using a questionnaire format. A more recent actigraph study of long range CC-130 operations was performed by Donati[7]. These, as yet unpublished, data provided experience with the use of actigraph monitors for studying aircrew in an operational environment. In the Donati study, a single aircrew was monitored during long haul flying between Canada and Somalia.

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<sup>2</sup>Bartlett hypothesized that mental fatigue effects become significant long before physical symptoms occur.

The invasion of Kuwait in the summer of 1990 led to a massive military build-up in Saudi Arabia, including a significant number of long range flights by military aircraft. The buildup and subsequent conflict provided ample opportunity for field studies of aircrew work/rest cycles.

Neville et al. [8] reported on subjective fatigue of USAF C-141 crews during the Persian Gulf war. Aircrews flew nominal 16 hour days (unaugmented) which were often extended to 20 hours. Flight records, activity logs, temperature data, and aircraft digital flight data were collected; and two fatigue scales were administered. The authors found that fatigue was related to 48-hour flight history; 10 hours of sleep in a 48 hour period was not sufficient for recovery. More than 15 hours of flying in a 48 hour period was also linked to high fatigue. The authors identified the need for careful 'fatigue management' in airlift operations, including (1) paying close attention to on-the-ground and on-board sleeping facilities for aircrew, and (2) fatigue management training for transport aircrew.

In a similar study of USAF C-5 operations during the force build up for the Persian Gulf War (Operation Desert Shield), Bisson et al. [9] found comparable results. Activity logs and flight records were used to collect information on crew performance. Aircrew reported moderate to extreme fatigue ratings on cross-ocean and round-trip flights. Periods of 8 to 18 hours cumulative airborne time were reported in a 24-hour period. Aircrew with late night take-off times reported being awake an average of 10.3 hours before flying. Difficulties falling asleep and restless sleep were also common complaints of aircrew required to make significant circadian shifts.

These previous studies of aircrew work/rest cycles in operational settings provide a wealth of suggestions for test instruments [5,8,9]. Two instruments were selected to measure work/rest data: Neville's questionnaire and activity monitors (actigraphs).

## METHOD

*Subjects.* Boxtop 1/95 assigned aircrew consisted of 45 adults - 43 males and 2 females. Participation in this study was voluntary and data were received from 41 people (91% participation). CC-130 aircrew positions include three officers: the Aircraft Commander (AC); the Co-Pilot (CP); and the Navigator (NAV). There are two other ranks positions to complete the standard CC-130 crew of five: the Flight Engineer (FE) and the Loadmaster (LM). Four crew members have cockpit stations; the Loadmaster works primarily in the rear of the aircraft.

Aircrew ranks ranged from Master Corporal (MCpl) through to Major (Maj) and years of military service<sup>3</sup> ranged from 3.5 to 31. Experience differences exist among the crew

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<sup>3</sup>"Tombstone" data on air crew were collected from two questionnaires handed out at Boxtop, but not discussed in this paper.

members: Flight Engineers on the CC-130 are required to have experience on other aircraft before converting to the Hercules, and they must have attained the rank of Sergeant. Under recent changes to ATG regulations, pilots cannot become a CC-130 Aircraft Commander during their first tour (a 'tour' or 'posting' is typically 3 to 5 years). The Navigator, Loadmaster, and Co-Pilot Positions may all be filled by personnel who have just completed basic training (in the case of the CP position, this means basic flying training, plus the CC-130 conversion course.)

Total military flying experience reported by Boxtop 1/95 aircrew ranged from 450 hours to 8400 hours, with a mean of approximately 2750 hours and a standard deviation of approximately 2025 hours. Reported CC-130 (type) experience ranged from 100 to 7500 hours, with a mean of approximately 1700 hours and a standard deviation of approximately 1630 hours. On average, the AC was the most experienced member of the crew on type, although there was no significant difference between AC experience and LM experience in pairwise comparisons. The CP was the most type-inexperienced member of the CC-130 crew. Mean flying hours on the CC-130 are presented in Table I.

Table I: Mean CC-130 Experience for Boxtop 1/95 Aircrew (hours)  
(sample size in parentheses)

Aircraft Commander (8)	2550
Co-Pilot (7)	281
Navigator (8)	885
Flight Engineer (9)	2200
Loadmaster (9)	2286

Boxtop 1/95 crews were scheduled to work a nominal 16 hour day<sup>4</sup>, followed by 32 hours of rest. Crew rest is defined as any time not spent working, and includes both sleep and wake time. Crews were scheduled to start in three groups of three, as shown in Table II. For each group, crew call-out times were staggered to reduce the chance of congestion on the ground at CFS Alert. Using nine crews and three aircraft results in a 48 hour cycle.

*Procedure.* Activity monitors were given to four of nine crews participating in Boxtop 1/95. Of 20 possible subjects, 18 volunteered to wear activity monitors (model AMA-32, by Precision Control Design Inc., Fort Walton Beach, Florida.) Additionally, aircrew were asked to complete a daily activity log, described below.

Subjects were allowed to wear the activity monitors on either wrist, using a light nylon watch strap. They were asked to wear the actigraph at all times, including sleep

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<sup>4</sup> Under ATG regulations, the maximum allowable crew day is 18 hours.



periods, except for showering and unusually vigorous exercise. Subjects were asked to note on their activity logs periods when the activity monitors were not worn.

Table II: Boxtop 1/95 Crew Call-Out Schedule

Crew	Call-Out Time
51	6:00 a.m., Day 1 (morning shift)
61	7:30 a.m., Day 1 (morning shift)
92	9:00 a.m., Day 1 (morning shift)
41	2:00 p.m., Day 2 (afternoon shift)
31	3:30 p.m., Day 2 (afternoon shift)
91	5:00 p.m., Day 2 (afternoon shift)
21	10:00 p.m., Day 1 (night shift)
62	11:30 p.m., Day 1 (night shift)
52	1:00 a.m., Day 2 (night shift)

The second instrument used to collect data on work/rest cycles was an activity log. A two-page activity log used by Neville et al. [8] was adapted for the study and reproduced using two sides of a single sheet of paper for each day of the operation. An example is given at Annex B. In order to encourage continuing participation by aircrew, it was decided to give out the logs at the beginning of every crew shift (i.e. every two days.) Initially this was done by handing ten blank copies to the Aircraft Commander as he reported to Boxtop operations at the start of a new shift. After the aircrew were familiar with the sleep logs, they were inserted into the satchel given to each Aircraft Commander at the beginning of his shift. Additional logs were kept in the operations area for use as needed.

All 45 aircrew had the opportunity to participate in the activity logs. Actual participation was 41. Participants were asked to identify themselves using the last three digits of their service number plus their initials. Identification was necessary to compare the three different crew start times. Some individuals were concerned that use of their service numbers would compromise their anonymity and as a result only 32 (71%) of the aircrew who participated could be assigned to a crew.

#### DIFFICULTIES ENCOUNTERED WITH FIELD DATA COLLECTION

*Actigraphs.* Because of the duration of the operation, it was decided to perform a data download from the actigraphs at approximately half-way through the Boxtop operation. The devices were retrieved from the aircrew, down-loaded, and the batteries replaced. The actigraphs were then re-initialized and returned to the aircrew. Since four crews were involved, representing each of the three groups of scheduled starting times, the actigraphs could not be returned immediately. Due to difficulties

down-loading data from the actigraphs, data were obtained from only one of the 18 devices at the half-way point.

The actigraphs were checked again after four days. No data could be down-loaded at that point, so the devices were not returned to the aircrew. After returning to DCIEM, it was discovered that the actigraphs had functioned properly during the four day period after the first down-load was attempted. It appears that difficulties with the computer used for the down-load were the source of the unsuccessful data transfer. The actigraphs had been sent out for service four months before the field trial and were not returned to DCIEM until the week before Boxtop. Accordingly little time was available to test the updated equipment.

*Activity Logs.* Problems with the format of the sleep log became apparent quickly. The long crew days and 48 hour crew cycle led to confusion about how to record data. Some subjects took more than one significant sleep period in 24 hours. Others did not know which meals to identify as breakfast, lunch, and supper. For example, aircrew starting at 2:00 p.m. might have their first meal of the day at 1:00 p.m. - is it breakfast or lunch? For many subjects, their work day spanned two calendar days. Deciding which date to enter on each activity log was also unclear. When these problems were identified to the experimenters, subjects were told to try and be consistent and make notes on the logs to explain their responses. For most participants, the result was usable, albeit difficult to interpret information. However, with night crews (those with call out times at 10:00 p.m., 11:30 p.m., and 1:00 a.m.) it was difficult to determine whether the day they were reporting on was a flying day or a rest day.

The activity logs were often not completed first thing in the morning or last thing at night as requested at the top of the page. Some crews completed the forms in the air between Thule and Alert. Most of the requested information was provided, but some was omitted and some was entered inconsistently. For example, some subjects used 24-hour times; others used 12-hour times; still others alternated between the two systems. Data inconsistencies were found: for example, the 'wake' page asked about the number of times a subject awakened during the night. Subsequent questions asked aircrew to say 'how many times for bathroom', 'how many times for noise', etc. The sum of these subsequent questions did not always equal the response to the first question. Subjects' sleep periods were identified by asking: time in bed, lights out time, minutes until fell asleep, and wake-up time. In many instances, at least one of these was omitted, reducing the number of valid responses.

*Environment.* Finding an opportunity to brief all the aircrew was difficult. The study was introduced and briefly explained as part of the operational briefing the day before Boxtop began. However, the available time was restricted and a well organized and speedy briefing was necessary. On a Boxtop operation, accommodation in either Thule or Alert is difficult to obtain, requiring a minimum of personnel. Arranging for

someone to be present to collect sleep logs at each crew call-out was difficult, and some pick-ups were missed.

## RESULTS AND DISCUSSION

*Actigraphy.* Eighteen aircrew wore actigraphs and data were retrieved from 15 of 18 for a four day period during Boxtop. Sleep periods were determined from the actigraph data using a standard algorithm [10]. The resulting graphs were compared with activity log data reported by the aircrew. On a case by case basis, subjects appeared to be good at estimating their lights out time (i.e. the time they began trying to go to sleep) and their wake-up time - differences of up to 15 minutes were noted. However, they appeared to be less able to estimate the time it took to fall asleep, used in the calculation of estimated sleep length. Significant discrepancies were also seen in the number of times awake, and the amount of time awake. However, it cannot be established whether these differences were due to subjects' estimation abilities or uncertainty in the actigraph sleep scoring algorithm.

The actigraph count data<sup>5</sup>, recorded at 30 second intervals, were selected for incidences of three-trip flying days. For each crew, data were available for exactly one three-trip day. Analysis of variance was used to compare mean activity levels within shifts for the three trips; individual and shift analyses were performed. Table III presents the results. All three shifts showed significant differences<sup>6</sup> in activity levels among trips.

Table III: Mean Activity Scores by Shift

Shift	Trip 1	Trip 2	Trip 3
Morning	58.00	56.71	57.59
Afternoon	50.02	49.77	47.39
Night	53.04	50.53	52.64

Table III shows changes in activity levels from trip to trip with each crew. Morning and night crew activity levels drop from first to second trip, then climb again for the third; the third trip activity level does not reach the first trip level. In contrast, afternoon aircrew decline in activity level from first to second trip, and from second to third trip. Activity level trends of morning and night crews support comments

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<sup>5</sup>Actigraphs make 0/1 assignments of movement at a fixed sampling rate, and sum over a pre-determined interval (in this case, 30 seconds) to produce a 'count' that is recorded.

<sup>6</sup>All differences between data sets were tested using the SAS system analysis of variance test. 'Significant differences' are those which are due to chance less than 5 times in 100.

reported by Boxtop 1/95 aircrew that the second of three trips was the 'hardest'. No significance should be drawn from activity level comparisons among shifts for a given trip. While the activity values show large variation, this could be the result of variation among the actigraphs, and/or individual differences (small sample size).

Since actigraphs measure movement, background vibration may affect the performance of the device. If background effects are too great, it may not be possible to determine, for example, periods of sleep in an aircraft. In a recent paper [13], Sadeh et al. noted that externally induced movement can affect actigraph recordings to the point where a person sleeping in a moving vehicle cannot be distinguished from one who is awake. While this latter point could not be confirmed, significant background effects were observed. On the return trip from Thule, all the actigraphs were packed into a padded case which was shipped by CC-130 and each printout shows a significant trace for all airborne periods (see Annex C: the period from 0800 hours on the day identified by trace line number five on the y-axis of the graph through 0130 hours on the day identified by trace line 6 on the y-axis of the graph). The Cole and Kripke sleep scoring algorithm could not identify the devices as being stationary. However, this factor is probably not significant for Boxtop 1/95 data due to the short length of each flight.

*Sleep Cycles.* Aircrew did not go to bed at the same time every night; nor did they sleep for the same number of hours each night. From the activity logs collected, 319 sleeps could be identified over all subjects and all days of the operation. Estimated sleep time<sup>7</sup> ranged from 30 minutes to 13 hours and 50 minutes for the longest single sleep period in 24 hours. The mean value was 7 hours 11 minutes, with a standard deviation of 2 hours 16 minutes.

When the estimated sleep data are divided up by aircrew shift, the number of available records drops to 261. The mean sleep length by shift and standard deviation are shown in Table IV. Mean estimated sleep lengths were compared using analysis of variance and found to be significantly different.

Table IV : Mean Estimated Sleep Length by Shift

Shift	Mean	Std Dev	Sample Size
Morning	7 h 35 min	1 h 48 min	103
Afternoon	7 h 10 min	1 h 59 min	81
Night	6 h 25 min	3 h 32 min	77

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<sup>7</sup>Sleep time was estimated by wake-up time minus lights out time minus time to fall asleep minus total time awake during the sleep. Actigraph comparisons indicate that subjects were good at estimating lights out time and wake-up time, but varied in their estimates of time to fall asleep.

Mean sleep length for the first five days (17-21 April) was not significantly different from that of the last five days (23-27 April) of Boxtop 1/95 in total, or by shift<sup>8</sup>. However, examination of individual data shows sleep lengths alternating between flying and resting days. Figure 1 shows sleep length vs. date for Subject 001. Long sleeps on even numbered days occurred after completion of a flying cycle.

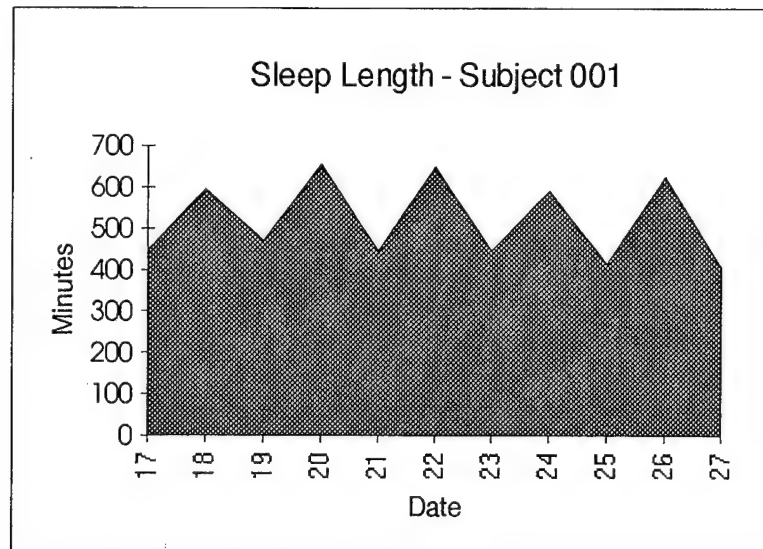


Figure 1: Sleep Length vs. Date for Subject 001

Each subject's estimated sleep lengths were divided into two groups, one for sleep after flying and one for sleep after a rest day. Some data were omitted because it was not possible to determine which day was flying vs. rest; others were deleted because of duplicate dates. A total of 252 valid sleeps remained. Mean estimated sleep after flying was 8 hours 20 minutes, with a standard deviation of 1 hour and 2 minutes. Mean estimated sleep after a rest day was 6 hours 17 minutes with a standard deviation of 1 hour and 49 minutes. The two means are significantly different.

Significant variation in sleep patterns has been recognized as contributing to decreased performance in flying [11]. As the amount of sleep decreases, flight crew can expect to take longer to recognize warning cues, understand their significance and act on them. As noted earlier, Neville et al. [8] found that fatigue was related to 48-hour history of sleep and flight time. Ten hours sleep or less in 48 hours was not sufficient protection against fatigue, and 15 hours or more flight time was associated with high subjective fatigue ratings. On average, Boxtop aircrew received sufficient sleep, but the long crew days experienced in some cases are a warning sign of potential fatigue.

*Time awake before first take-off; Time continuously awake.* A long time awake before the start of the duty day is an indication that aircrew are not adjusting to an unusual shift.

<sup>8</sup>April 22 was a flying day. It is omitted here to balance the number of days compared.

Time awake before duty was estimated by the difference between wake time and time of first take-off on a flying day. Using first take-off time is a relatively poor estimator of the beginning of the duty day. A better estimator would be the crew call-out time; however these were not recorded. Under routine transport operations the aircrew, especially the flight engineer, may be on duty several hours before the take-off time. However, during Boxtop operations, the aircraft are usually not available for pre-flight activity too early, and operations staff call out crews with the intention of a minimum wait before first take-off.

From the sleep log data, hours awake before take-off could be calculated in 115 instances. These data were analyzed using analysis of variance and grouping by shift. Mean time awake before first take-off is shown in Table V. The means are significantly different. Aircrew on the afternoon shift were up the longest before flying: an average of 5 hours 4 minutes. It was initially expected that night crews would be up longer before flying, because of disturbed circadian rhythms. On closer examination of the data, it was found that, in contrast to their colleagues, night crews often napped for two to four hours before flying.

Table V: Mean Time Awake Before First Take-Off

Shift	Mean	Std Dev	Sample Size
Morning	2 h 47 min	1 h 17 min	46
Afternoon	5 h 4 min	2 h 55 min	44
Night	3 h 16 min	1 h 47 min	25

Using the same set of data, it is possible to estimate the time continuously awake when aircrew make their last landing. As an estimator for this value, the last landing time from the K-1017 form<sup>9</sup> was added to the time awake before flying, less thirty minutes to approximate the time to begin final approach. Data were analyzed by number of trips flown. Results for three trip days are presented by shift in Table VI.

Table VI: Estimated Mean Time Awake on  
Last Final Approach (3 trip days)

Shift	Mean	Sample Size
Morning	15 h 4 min	24
Afternoon	17 h 19 min	35
Night	16 h 11 min	10

<sup>9</sup>The K-1017 form is Air Transport Group's 'Flight Authorization and Record of Flight' form. It is completed for each flight of a CC-130 aircraft. More detail on the K-1017 is available from the author.

While mean values show typical aircrew condition, it is interesting to look at the extreme cases for hours awake on last landing. Using touch-down times from the K-1017 form and reported wake-up times for aircrew, the four largest values for continuous hours awake on last touch-down are: 23 hours 55 minutes, 24 hours 35 minutes (2 cases), and 25 hours 5 minutes. The ten largest values of continuous time awake are all from crews on the afternoon shift. Note that afternoon crews flew, on average, more trips per day than did morning or night crews - because of weather and aircraft maintenance problems - so there was more opportunity for these crews to have been up for long hours on their last landing.

*Sleep Quality.* While the mechanisms are not well understood, mood, sleep quality, and alertness on awakening are important indicators of fatigue (e.g. [8, 12]). On their activity logs, aircrew were asked to rate sleep quality, mood on awakening, and alertness on awakening on a seven point scale. Adjectives were provided for the lowest and highest values (see Annex B) and all scales associated a score of one (1) with the poorest rating and seven (7) with the best rating.

Comparative data were not collected before or after Boxtop, so the absolute ratings cannot be commented on. However, changes in ratings and differences between shifts are of interest. Table VII presents results on a per shift basis. Analysis of variance established statistically significant differences among the means on all three scales. While pairwise testing was not done, the significances seem to be due to the night shift which scored lower, on average, on all three scales. Night crews were not sleeping as well, were not as positive, and did not feel as alert as morning and afternoon crews.

Table VII: Mean Mood, Sleep Quality, and Alertness Ratings by Shift

Shift	Mood	Sleep Quality	Alertness on Wakening
Morning	5.05	4.84	4.77
Afternoon	5.08	4.81	4.73
Night	4.02	4.03	3.91

Mood, sleep quality and alertness on awakening were also compared for the first few days (17-21 April) vs. the last few days (23-27 April) of Boxtop. No significant differences were found, however mean values for the night shift aircrew were lower on all three scales for week two as compared to week one. In contrast, shift two aircrew showed improvement on all three scales between week one and week two.

Another, somewhat more objective measure of sleep quality is number of times a subject awakened during sleep. This measure has been associated with circadian shifts



and rapid shifts in sleep schedules [9]. Boxtop aircrew were asked to report number of times awake and the reasons. Of 370 valid sleeps, aircrew reported one or more wake episodes in 262 or 81% of cases. Fully 25% of sleeps were interrupted three or more times. Subjects who woke up one or more times were awake, on average, for a total of 31 minutes. Subjects were asked to say why they woke up: either for the bathroom, noise, discomfort, or other reasons. For reported values 29% were due to noise or discomfort. It was observed (and experienced!) by the experimenters that many complaints were due to the quality of accommodation at Thule Air Force Base.



## COMMENTS AND CONCLUSIONS

Although problems were encountered in data collection, this study succeeded in showing that activity data can be collected in the field. This success was due in no small measure to the excellent cooperation received from the Boxtop operations staff. Data collection instruments must be tested and customized before taking them to the field to avoid unforeseen difficulties in equipment usage and questionnaire format. The benefits of a field study are operational relevance, increased impact on decision makers, and a stronger commitment from aircrew.

In engineering, fatigue is defined as failure resulting from repeated applications of load [14]; it is also called *progressive* failure. In Boxtop operations, aircrew experience long working days over a period of up to two weeks. For aircrews, repeatedly approaching their crew day limit over an extended period of time provides a good environment for fatigue 'failures' to occur.

Baseline data were collected on an ATG operation. Evidence was found (some of it compelling) that in Boxtop 1/95, afternoon crews and night crews were disadvantaged, as compared to morning crews. While night crews tended to nap before flying, they reported significantly lower mood, sleep quality and alertness on awakening - indicating that the napping strategy was not completely effective. Afternoon crews did not nap, flew more trips, and possibly as a result, were more likely to have been awake longer than morning or night crews.

The data analysis in this report has focused primarily on mean values of measures such as sleep length and hours awake before flying. However, on average, every flight is expected to be incident free. The analysis of data for flight safety must include consideration of the extreme cases - because accidents are almost always the result of conditions that statistically would be considered as 'outliers'. This was illustrated by highlighting the very long days experienced by some crews.

Flying contains an element of risk, and the flight safety system exists to manage this risk. Using an analogy from the field of engineering, there is a safety margin between the operational needs of a mission and an incident or accident. Maintaining this margin is the responsibility of all members of the aviation community, including researchers. Prolonged flying operations should be monitored for symptoms of crew fatigue and a narrowing of the margin of safety. This study has investigated one way to add to the knowledge base of the CF aviation community and it has provided baseline data for future comparison.

This study, on its own, does not provide sufficient evidence of aircrew fatigue, or other flight safety considerations, to justify a reduction in the length of the Boxtop aircrew day. However, the data do suggest that the three trip day may be too long. A study comparing data from a two-trip-day Boxtop and typical ATG squadron operations would provide better evidence for decision makers.

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ANNEX A: Boxtop 1/95 Crew Callout Schedule

----- Morning Crews -----      ----- Night Crews -----      ----- Afternoon Crews -----

51	61	92	21	62	52	41	31	91
17/0600	17/0730	17/0900	17/2200	17/2330	18/0100	18/1400	18/1530	18/1700
19/0600	19/0730	19/0900	19/2200	19/2330	20/0100	20/1400	20/1530	20/1700
21/0600	21/0730	21/0900	21/2200	21/2330	22/0100	22/1400	22/1530	22/1700
23/0600	23/0730	23/0900	23/2200	23/2330	24/0100	24/1400	24/1530	24/1700
25/0600	25/0730	25/0900	25/2200	25/2330	26/0100	26/1400	26/1530	26/1700
27/0600	27/0730	27/0900						

Notes:

1. Times are planned callouts; actual times varied due to delays.
2. Each callout represents the beginning of a planned 16-hour duty day, including three Thule-Alert return trips. Not all trips were flown.
3. Top line of table is the crew number; crew numbers are derived from squadron numbers, e.g. crew 92 is the second crew from 429 squadron.
4. The table uses military style date-time groups, e.g. 17/0600 means the planned callout time for this crew is 6 a.m., 17 April, 1995; 26/1700 means 5:00 p.m., 26 April, 1995.

ANNEX B: Activity Log



**SLEEP DIARY : BEDTIME      KEEP BY BED**

PLEASE FILL OUT THIS PAGE LAST THING AT NIGHT

Day \_\_\_\_\_ Date \_\_\_\_\_ ID code \_\_\_\_\_

Today, what time did you have:    Breakfast \_\_\_\_\_ Lunch \_\_\_\_\_ Dinner \_\_\_\_\_

How many of the following did you have in each time period? (if none, write '0')

	before or with breakfast	after breakfast before/with lunch	after lunch before/with dinner	after dinner
caffeinated drinks	_____	_____	_____	_____
alcoholic drinks	_____	_____	_____	_____
cigarettes	_____	_____	_____	_____
cigars/pipes/plugs (of chewing tobacco)	_____	_____	_____	_____

Which drugs and medications did you take today? (prescribed & over the counter)

Name	Time	Dose
_____	_____	_____
_____	_____	_____
_____	_____	_____

What exercise did you take today? (if none check here \_\_\_\_\_)

start	_____	end	_____	type	_____
start	_____	end	_____	type	_____

How many daytime naps did you take today? (if none, check here \_\_\_\_\_)

give times for each:

start	_____	end	_____
start	_____	end	_____

RATINGS: (please circle the number that best reflects your present state)

MOOD AT BEDTIME:

1	2	3	4	5	6	7
very negative						very positive

ALERTNESS AT BEDTIME:

1	2	3	4	5	6	7
very negative						very positive

Why do you believe that you feel this way in terms of (please be brief):

YOUR MOOD: \_\_\_\_\_

YOUR ALERTNESS: \_\_\_\_\_

SLEEP DIARY : WAKE TIME KEEP BY BED

PLEASE FILL OUT THIS PAGE FIRST THING IN THE MORNING

Day \_\_\_\_\_ Date \_\_\_\_\_ ID code \_\_\_\_\_

went to bed last night at: \_\_\_\_\_ lights out at: \_\_\_\_\_ minutes until fell asleep: \_\_\_\_\_ finally woke at: \_\_\_\_\_

awakened by (check one) alarm clock/radio: \_\_\_\_\_ call out \_\_\_\_\_ noises \_\_\_\_\_ just awoke \_\_\_\_\_

after falling asleep, woke up this many times during the night (circle):  
0 1 2 3 4 5 or more

total number of minutes awake: \_\_\_\_\_  
- woke to use bathroom (circle # times)  
0 1 2 3 4 5 or more  
- awakened by noises/other people (circle # times)  
0 1 2 3 4 5 or more  
- awakened due to discomfort of physical complaint (circle # times)  
0 1 2 3 4 5 or more  
- just woke (circle # times)  
0 1 2 3 4 5 or more

RATINGS (please circle the number that best reflects your present state)

SLEEP QUALITY

1 2 3 4 5 6 7  
very bad very good

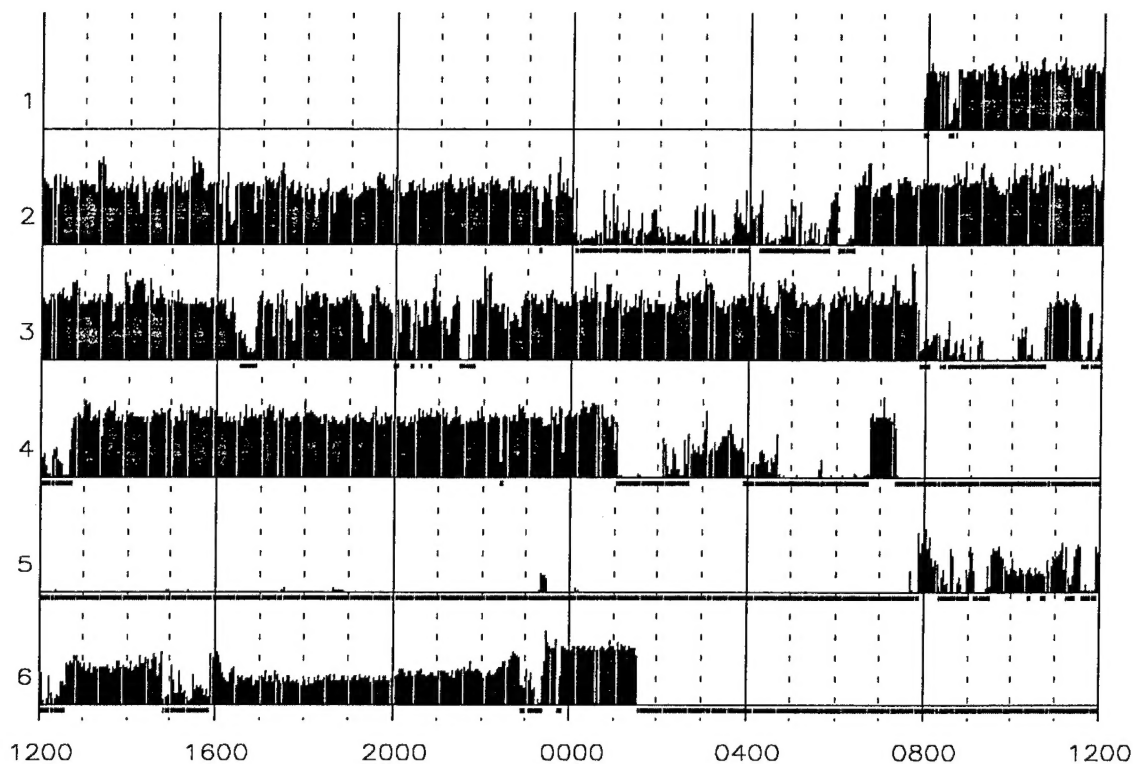
MOOD ON FINAL WAKENING:

1 2 3 4 5 6 7  
very negative very positive

ALERTNESS ON FINAL WAKENING:

1 2 3 4 5 6 7  
very sleepy very alert

ANNEX C: Sample Actigraph Plot



File: A30.DAT, Epoch: 30, Amplifier: 18, Scale: 110  
 Starting Time: Apr 22, 1995, 07:55:00, SN:0030  
 Sleep scoring algorithm: Cole and Kripke

Explanation: An actigraph, or activity monitor, records an activity 'count' over a pre-set time interval (30 seconds in this example.) The higher the activity over the interval, the larger the count. This graph is a pictorial representation of the basic count data from an activity monitor. The trace on this graph begins at the time the activity monitor was programmed to start recording data (April 22, 1995, 07:55). On this graph, the trace continues until the memory of the device was filled, about four and one-half days later.

This graph also shows the results of "sleep scoring" using the Cole and Kripke algorithm: portions of the trace underscored with a heavy line indicate periods of scored sleep. Periods when the activity monitor was not worn are identifiable by a flat trace (e.g. Day 5, 1200 - 1600.) A restless sleep is indicated when the sleep score line is broken in several places (e.g. Day 2, 0400 - 0600.)

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This paper reports on activity log data collected during Boxtop 1/95. Boxtop aircrew flew a fixed three-shift, three-airplane schedule repeating every 48 hours. A two-page activity log was used to collect data from 41 aircrew and wrist actigraphs were used to provide a second source of information from 18 aircrew. Information was collected on sleep length, hours awake before flying, hours continuously awake, mood, alertness and sleep quality. Significant differences were found between shifts, particularly the night shift which scored lower on mood, sleep quality, and alertness on awakening. Afternoon crews were up longer before flying and during their last touch-down of a work cycle, on average, than morning or night crews.

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